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TRANSLATION

THE STATIC MOMENTS OF THE COMPONENT MASSES
OF THE HUMAN BODY

By

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THE STATIC MOMENTS OF THE COMPONENT MASSES OF THE HUMAN BODY

BY: Dr. Harless

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THE STATIC MOMENTS OF THE COMPONENT MASSES OF THE HUMAN BODY

Borelli was the first to attempt to determine the center of gravity of the human body by experiment. For this purpose, he used a plank on which a cadaver was balanced over the rounded edge of a triangular wooden pin placed under it.

The inaccurate indication which Borelli gave for the position of the center of gravity (he designated it with the words "inter nates et pubin") prompted the Weber brothers to repeat the experiment in the course of their researches on "the mechanics of the human locomotive apparatus" and to make an exact determination of the position of the over-all center of gravity.

While their technique was essentially the same, they attempted to limit the possible and, indeed, inevitable errors to the minimum by means of a slight modification of the process.

They achieved this as follows:* they took a 7'-long, 1'-wide plank and laid it horizontally over the rounded edge of a second vertically positioned [plank] in such a way that the first plank was in exact equilibrium. They marked this position with two lines on the sides of the horizontal board at the point where the latter touched the vertical board and made certain at frequent intervals during the experiment that it had not shifted. Next, one half of the horizontal board was supported. The disrobed subject stretched himself out lengthwise on the board so that the center of gravity of

*Loc. cit., page 114.

the corporature was just on the side of the supported half of the plank. The head was on the same end of the plank. Then he inched as cautiously as possible, with slight movements of his spinal column, and maintaining the same relative positions of all his members, toward the unsupported end of the board, continuing until the weight on that end preponderated. Since the board had itself already been balanced, but, with the body on it, tilted at just this point toward the unsupported end, the center of gravity was then necessarily on the other side of the board's pivot axis. Now the experiment was repeated; this time, however, the head was placed on the side previously occupied by the feet; the center of gravity again occurred on the supported half of the plank. As before, the human subject edged his body far enough along the board so that the center of gravity crossed to the other side and the plank again teetered in this direction. In each of the two experiments, a plumbline was dropped from the top of the head to the board and a note made of the point at which it fell. One-half of the distance between these two points gave the distance of the center of gravity from the top of the head. The accuracy of the procedure will become evident when we recall that equilibrium, which is so difficult to attain, need not be established perfectly, and that measurement errors of opposite signs cancel each other.

The brothers Weber found, as an average of several experiments on the same individual, the value of

721.5 millimeters

for the distance of the center of gravity from the top of the head.

The total height of the outstretched body was 1669.2 mm; the distance of the center of gravity from the heels was accordingly

947.7 millimeters.

If we set the total height equal to 1000,

the distance of the over-all center of gravity

from the top of the head is 432.24

from the heel is 567.76.

By comparative measurements made on the skeleton of a cadaver of the same height, they arrived at a more anatomical determination of the location of the over-all center of gravity: they found it to be vertically above the promontorium, at a distance of 8.7 millimeters therefrom.

It is doubtless unnecessary to note that this location must be subject to variation in one and the same individual, even with the limbs remaining in exactly the same positions, when we take into consideration the varying degrees to which our intestine is filled and, moreover, when we give attention to the changes that take place in the curvatures of the spinal column on transition from the erect to the horizontal posture.*

However, the prime interest is aroused by the question as to how large the variations of this location may be between different individuals. I take note first of an experiment of my own design, since it was set up in exactly the same way as prescribed by the brothers Weber on a very well-developed 24-year-old man.

The total height was 1655 millimeters.

The distance of the center of gravity from the soles of the feet averaged 970 mm.

For the total height set equal to 1000, this corresponds to

586.102 from the soles

413.898 from the top of the head.

*Fr. Horner: Ueber die Kruemmung der Wirbelsaeule im aufrechten Stehen (Concerning the curvature of the vertebral column in the standing position), Inaugural Dissertation, Zuerich, 1854, page 22.

The difference between my determinations and those of the Webers is accordingly 1.83 percent of the total height.

Valentin* found his distance from the top of the head to be 429.19.

This type of measurement permits only determination of the horizontal plane in which the center of gravity of the whole body lies, and not determination of the point in this plane that it occupies. It is, however, precisely for balancing between planes parallel to that passed from right to left through the body that determination of its distance from the ventral or dorsal limiting line of the profile becomes important.

H. Meyer proposed an accurate way to do this in his estimable "Beitraege zur Mekhanik des menschlichen Knochengeruestes" ("Contributions to the Mechanics of the Human Skeletal Apparatus").** He uses a scale with movable arms and a graduated circle for direct measurement of the angle formed on the latter by the whole leg axis and torso, which was, for itself, held stiff, with the foot as the individual raises himself up onto his toes, and notes firstly the moment at which the heel leaves the floor for the known leg length and known angle of inclination of the leg axis in the standing position and, secondly, the moment at which the entire body shifts forward about the midpoint of the head of the first metatarsal. The angle at which the metatarsal head of the big toe leaves the floor when the body in itself is held rigid and moved backward on the ankles is determined in the same way.

From this we may derive the horizontal displacement of the center of gravity for the determinable distance of the promontorium from the

*Lehrbuch der Physiologie des Menschen (Textbook of Human Physiology), Vol. IIa, page 331.
**Published in J. Muellers Archiv (J. Mueller's Archives), 1853.

trochanter and calculate its distance from one or another point of the leg or some other part of the body. In the individual studied by Meyer, the center of gravity in the standing position lay at a horizontal distance of 3.28 cm in front of the external malleolus, 10.72 cm behind the head of the first metatarsal, and 5.22 cm behind the front margin of the trochanter. According to his data, the center of gravity was 9.5 cm above the pivot axis of the hip joint, which strikes the peaks of the two greater trochanters. If we pass a line from the center of gravity to the midpoint of this axis, it will be inclined at an angle of $52^{\circ}23'$ to the horizontal in the standing position.

Anatomically, Meyer indicated the canalis sacralis above the second sacral vertebra as the locus of the center of gravity.

In his case, the center of gravity of the 1897-mm-tall body occurs 768 mm from the top of the head. For the total height taken as 1000, however, this gives distances of

404.96 from the top of the head

595.14 from the soles of the feet.

In this case, the deviation from the Weber results comes to

2.73 percent of the total height.

The average value for the distance from the top of the head, as obtained from four observations conducted on different individuals, comes to 420.07 on a total height of 1000.

The over-all center of gravity of the body is placed at this specific point by the distances of the centers of gravity of all of its individual members. If we now wish to form a conception of its migrations for different attitudes of the corporature, it will be necessary to attempt to isolate the centers of gravity for the largest possible number of movable masses. The loci of the centers

of gravity of certain parts of the body, e.g., the head, the lower extremity, the torso, have been computed separately for various purposes. This was done very recently by Horner.* I shall pass over these data at the moment, because they were obtained in isolation and because some average values and some individual values were employed in the calculations, without going into the matter of their value for the investigations concerned.

Herr Professor Dr. Bischoff had the kindness to provide me with the corpse of one recently executed Graf for use in my investigations.

I must first preface the discussion that follows with certain remarks concerning the method used. It was my objective to find the horizontal planes in which the centers of gravity of the individual component masses were located. Equilibriation must be regarded as the best means to this end. The apparatus used was as follows: a graduated rod was secured in an absolutely horizontal position. A pulley whose groove was equal to the thickness of the rod ran along its flat edge. A broad brass yoke was riveted to the shaft about which the pulley turned; its height was equal to the width of the rod. The yoke had a cutout at one side, through which the graduations of the rod were visible, and a tongue-shaped indicator in the middle, the point of which stood vertically below the pivot axis of the roller.

An iron stirrup carrying a horizontal iron rod at the bottom was secured to the lower end of this yoke. The ring was made large enough to permit it to encompass the thigh without discomfort. A board was balanced on the lower horizontal rod and the individual parts placed on it. As in the Weber experiment, the procedure of

*Loc. cit.

twice-repeated loading and tilting was followed to limit the errors.

The roller made it possible to obtain extremely fine displacements of the substructure under the preparation with the indicator pointing directly to the numeral in question, while sliding squares laid against the appropriate boundaries of the member immediately gave the distances of these boundaries from one another as soon as the lower plank was readjusted parallel to the upper rod. The average of the readings gave the distance of the center of gravity from the two ends of the member under investigation.

The manner in which the individual members must be separated from one another is of greatest importance.

If it is a matter of determining the magnitude of the static moment in each individual position, the boundary of the mass must coincide with that of the lever arm. Thus the planes of separation of the members must be tangent to their planes of articulation. Accordingly, the upper arm was severed by passing the cut through the walls of the armpit almost flush with the torso and parallel to its sagittal plane, exarticulating, and then cutting out through the [deltoid*] under the acromion at right angles to the first plane.

A circular incision in the plane of the pivot axis of the upper- and forearm severed the elbow joint. Likewise, a similar cut at the level of the processus styloideus ulnae separated the hand from the forearm.

For the thigh, the cut was passed through from the symphysis ossium pubis, close to the pelvic bones; then the head of the femur was exarticulated and the muscles cut through horizontally directly above the head in the lateral direction. The other parts of the lower extremity were separated from one another in much the same way as

*[Translator's note: Literally, "shoulder cover."]

the corresponding parts of the upper extremity.

To prevent the uneven contraction of the soft parts at the two ends from exerting an excessive detrimental influence on the center-of-gravity determination, they were sutured together over [the bone ends] in about the same way as the skin flaps of an amputation stump.

Immediately thereafter, each preparation was weighed on a precision decimal balance.

The length measurements were as follows:

Total height 172.685 centimeters.

The component measurements gave:

Height of foot	6 Centimeters
Length of shank	42.9 "
Length of thigh	44.9 "
Distance of trochanteric line from the <u>crista ossis ilei</u>	14 "
Distance of plane of ileum from plane of <u>acromion</u>	39 "
Height of head from chin to top of head	21.2 "
Height of neck at front	4.7 "
	172.7 Centimeters

The length of the foot was 25.369 cm.

Total length of the arm was	86.6 cm
Length of upper arm	36.4 cm
Length of forearm	29.889 cm
Length of hand	20.314 cm
	86.603 cm

If we set the total height of the body equal to 1000, we obtain the following supplementary measurements:

Length of head and neck together	149.97
Length of torso	306.9
Length of entire leg	543.1300
	100.000 [sic]

For subsequent determinations, the trunk was separated into two parts, of which the larger, upper part had a length of 225.82 from the crest of the ilium to shoulder level, and the lower part measured 81.1 to the mons.

The total length of the arm is	501.75
Length of upper arm	211.06
Length of forearm	173.07
Length of hand	117.62
Length of foot	147
Length of shank	248.405
Length of thigh	259.99

If we select the length of one of the members — i.e., the length of the hand — as a unit of measurement for comparison with all others, we obtain the following values:

Hand	= 1
Head and neck	1.2749
Torso	2.6090
Entire leg	4.6175
Upper torso	1.9
Lower torso	0.69
Entire arm	4.263
Upper arm	1.7918
Forearm	1.471
Length of foot	1.243
Shank	2.111
Thigh	2.2102
Entire body	8.50

The weights of the individual parts were as follows:

Total weight		63.97 kg (before execution)
Weight of head		4.555 kg
Weight of torso		29.608 "
Weight of both arms		7.54 "
Weight of both legs		22.27 "
Average weight	of single hand	540 grams
	of single forearm	1160 "
	of single upper arm	2070 "
	of single thigh	7165 "
	of single shank	2800 "
	of single foot	1170 "

Since the trunk is itself articulated, it was desirable at least to dissect it into several pieces whose patterns of movement could be reduced to reciprocal angular bending motions. Considered as a less highly articulated staff, the vertebral column can be most conveniently divided in accordance with its actual mobility into three pieces that form angles with one another in the various positions. The lowermost part was composed of the sacrum and first lumber vertebra, the middle part of the remaining lumbar vertebrae and thoracic vertebrae, and the upper part of the cervical vertebrae and the head.

I do not deny that this division is somewhat arbitrary and that it would be more natural to include at least one more member (speficically, that formed by the lumbar vertebrae); but simply on account of the impossibility of determining exactly the shapes of the masses included by the horizontal planes of these boundaries, the calculations would be made less accurate, and nothing essential would have been gained on the accuracy inherently available in this work.

It will be appreciated that calculations must supplant direct

weighing in determining the weights of the individual sections of the torso, since it is impossible to follow anatomical planes of separation in this case.

The upper part of the torso down to a point under the crests of the ilia may be regarded as a truncated cone. Averaged depth and breadth measurements gave a calculated value of 24.9 cm for the diameter of this cone at the top and 26.3 cm at the bottom. The height of the cone amounted to 41 centimeters.

Now the following formula applies for the volume of the truncated cone:

$$V = \pi(r_1^2 + r_1 r_2 + r_2^2)\frac{h}{3} ,$$

where r_1 is the larger radius and r_2 is the smaller radius, and h is the height.

Thus we obtain the following calculations for our case:

$$\begin{aligned}
R_1 &= 13{,}15 \quad \lg R_1 = 1.1189258 \\
R_2 &= 12{,}45 \quad \lg R_2 = 1.0951694 \\
\lg R_1 R_2 &= 2.2140952 = 163.72 \\
\lg R_1^2 &= 2.2378516 = 172.92 \\
\lg R_2^2 &= 2.1903388 = 155.89 \\
\lg R_1^2 + R_1 R_2 + R_2^2 &= \lg 491.53 = 2.6915500 \\
\lg \tfrac{h}{3} &= 1{,}1355389 \\
\lg \pi &= 0.49715 \\
\lg V &= 4.3222389 = 21100
\end{aligned}$$

The value of V is in cubic centimeters and therefore corresponds to the weight [sic] of an equal number of grams [sic] of water.

According to the determinations of Harkness and Baumgartner, the specific gravity of the entire human specimen may be assumed equal to 1.066. The above value must therefore be multiplied by this figure.

$$\begin{aligned}
\lg 1{,}066 &= 0.0277572 \\
\lg V &= 4.3222389 \\
&\ 4.3499961 = 22.387 \text{ kg.}
\end{aligned}$$

The lower part of the torso, i.e., the pelvis, must be regarded as a space with approximately elliptical surfaces and a volume given

by the formula

$$V = \frac{\pi h}{6} [2 (ab + a_1b_1) + ab_1 + a_1b]$$

Here, a and b are the semiaxes of the larger elliptical surface and a_1 and b_1 those of the smaller elliptical surface; specifically, a and a_1 are the semimajor and b and b_1 are the semiminor axes; h denotes the height.

Measurements on the cadaver under study gave the following values:

$$
\begin{array}{lll}
a = 17 \quad \lg = 1{,}2304489 & & \\
b = 11 \quad \lg = 1{,}0413927 & \lg ab = 2{,}2718416 = \text{num. } 187 & \\
a_1 = 10 \quad \lg = 1{,}0000000 & & \\
b_1 = 8{,}9 \quad \lg = 0{,}9493900 & \lg a_1b_1 = 1{,}9493900 = \text{num. } 89 & \\
 & \text{Sum} \quad 276{,}0 \times 2 = & \\
 & 552{,}0 & \\
h = 13{,}5 \quad \lg = 1{,}1303338 & \lg a_1b = 2{,}0413927 = \text{num. } 110{,}00 & \\
 & \lg ab_1 = 2{,}1798389 = \text{num. } 151{,}30 & \\
 & \text{Sum} = 813{,}30 = & \\
 & 2 (ab + a_1b_1) + ab_1 + a_1b2 &
\end{array}
$$

$$
\begin{aligned}
\lg \pi h &= 1{,}6274838 \\
\lg 6 &= 0{,}7781513 \\
\lg \tfrac{\pi h}{6} &= 0{,}8493325 \\
\lg 813.3 &= 2{,}9102508 \\
&\ 3{,}7595833 = \text{num. } 5768{,}9 = V
\end{aligned}
$$

Multiplying the values of V by 1.066 gives the weight as

6.1283 kg for the lower part of the trunk.

The weight of the upper part was

22.387 kg, and hence the weight of the entire

torso was 28.5153 kg. The balance had given its weight

as 29.608 kg.

This yields a difference of 1.0927 kilograms. In accordance with the two masses, the difference may be distributed by adding 0.668 to the calculated weight of the upper piece and 0.4000 to that of the lower piece, so that the weight of the upper part of the torso may be assumed to be 23.055 kg and that of the lower part 6.553 kilograms, as values that correspond most closely to actuality.

Thus one factor for computing the static moment of each individual member has been obtained.

The second factor is the length of the lever on which these

masses work, i.e., the distance from the center of gravity to the boundaries of the members.

Direct measurements by the method reported above gave the following average values for the locus of the center of gravity:

1) for the upper arm (length 36.4 cm)	17.621 from the upper end 18.779 from the lower end
2) for the forearm (length 29.889 cm)	13.122 from the upper end 16.767 from the lower end
3) for the hand (length 20.314 cm)	9.623 from the upper end 10.691 from the lower end
4) for the thigh (length 44.9 cm)	20.995 from the upper end 23.905 from the lower end
5) for the shank (length 42.9 cm)	15.455 from the upper end 27.445 from the lower end
6) for the foot (length 25.369 cm)	11.664 from the heel 13.705 from the toe
7) for the head (height 21.2 cm)	7.7 from the top 13.5 from the chin

It was necessary to locate the center of gravity for the above-described two parts of the torso by calculation.

In the truncated cone, the following formula applies for the vertical distance of the center of gravity from the base:

$$z = \frac{R_1^2 + 2R_1R_2 + 3R_2^2}{R_1^2 + R_1R_2 + R_2^2} \cdot \frac{b}{4}$$

Now, as above, we have

$$\begin{array}{llll}
R_1 = 13{,}15 & \lg R_1 = 1{,}1189258 & \lg R_1^2 = 2{,}2378516 & \text{num } 172{,}92 \\
R_2 = 12{,}45 & \lg R_2 = 1{,}0951694 & \lg R_1R_2 = 2{,}2140952 & \text{num } 163{,}72 \\
b = 41 & \lg b = 1{,}6127839 & 2R_1R_2 = & 327{,}44 \\
 & & \lg R_2^2 = 2{,}1903388 = & \text{num } 155{,}00 \\
\frac{b}{4} = 10{,}25 & \lg \frac{b}{4} = 1{,}0086002 & 3R_2^2 = & 465{,}00
\end{array}$$

And, accordingly,

$$\begin{array}{ll}
\dfrac{172{,}92 + 327{,}44 + 465{,}0}{172{,}92 + 163{,}72 + 155} = \dfrac{965{,}36}{491{,}64} & \begin{array}{l} \lg \; 2{,}9846693 \\ \lg \; 2{,}6228769 - \\ \quad 0{,}3618124 \end{array} \\
 & \lg \frac{b}{4} \quad 1{,}0086002 + \\
 & \lg z = 1{,}3704126 = \text{num. } 23{,}465
\end{array}$$

The center of gravity of the upper part of the trunk accordingly lies at

23.465 cm from the lower boundary, and

17.53 cm from the upper.

It is permissible to use the same formula for calculation of the center of gravity of the lower part of the torso:

Here the average upper radius = R_1;

$R_1 = 14,\ \lg R_1 = 1{,}1461280 \quad \lg R_1R_2 = 2{,}121[illegible] \quad \text{num } 132{,}30$

$R_2 = 9.43\ \lg R_2 = 0{,}97[illegible] \quad \lg 2 = 0{,}3010300$

$\lg 2R_1R_2 = 2{,}4225[illegible] \quad \text{num } 264{,}60$

$h = 13.5\ \lg = 1{,}1303338 \quad \lg R_1^2 = 2{,}2922560 \quad \text{num. } 196{,}0$

$\lg 4 = 0{,}60206 \quad \lg R_2^2 = 1{,}9[illegible] \quad \text{num } 89{,}143$

$\lg \frac{h}{4} = 0{,}5282738 \quad \lg 3 = 0{,}4771213$

$\lg 3R_2^2 = 2{,}4279[illegible] \quad \text{num. } 267{,}905$

$\frac{196 + 264.60 + 267.905}{196.0 + 132,30 + 89.143} = \frac{728{,}505}{417{,}443} \quad \begin{array}{l} \lg = 2{,}8624296 \\ \lg = 2{,}6205941 \end{array}$

$0{,}2418355$

$\lg \frac{h}{4} \quad 0{,}5282738$

$\lg z = 0{,}7701093 = \text{num } 5{,}8899 \text{ C.}$

as the distance from the upper boundary and 7.6101 cm as the distance from the lower boundary.

If we now set the length of each part whose center of gravity has been located equal to unity, we obtain the following picture:

Designation of part of body		Distance of center of gravity from the upper boundary of the part		Distance of center of gravity from the lower boundary of the part
Head		0.36667		0.63333
Upper part of trunk		0.42756		0.57244
Lower part of trunk		0.43629		0.56371
Upper arm		0.48521		0.51479
Forearm		0.43887		0.56113
Hand		0.47371		0.52629
Thigh		0.46760		0.53240
Shank		0.36025		0.63975
Foot	(from the heel)	0.45977	(from the toe)	0.54023
Average for all parts		0.435		0.565
Largest difference		0.125		

After both factors of the static moments had been determined in this way for all of the pieces listed, it was a matter of checking to see how well use of these values agreed with direct measurements.

I used the Weber method to determine the centers of gravity of the entire arm and the entire leg, each taken alone, on the body of

a criminal who had been executed four weeks previously, and who had also had a very powerful physique. These members were separated from the trunk in exactly the same way as described above. Moreover, the intervention of rigor mortis had been waited out so that the displacements on the board could be made with greater accuracy.

For the lower extremity, I used this method to find the vertical plane of the center of gravity (the entire leg thought of as lying horizontal and fully extended) at a position directly above the upper margin of the kneecap. In the case of the upper extremity, it was 1/2 cm above the condylus internus humeri.

In determining the centers of gravity of composite bodies, it is necessary to employ the formula for determination of resultants of parallel forces. Since we are concerning outselves here with only a single plane of projection, only a single formula will be put to use, and namely

$$X = \frac{Px + P_1x_1 + P_2x_2}{P + P_1 + P_2 \ldots}$$

where X is the distance of the center of gravity from the projection plane in question, P, P_1, and P_2... are the respective weights of the masses, and x, x_1, x_2... are the corresponding distances from the projection plane.

For the opposite case, the distances of the centers of gravity from the upper plane of separation were

For the thigh 20.995 cm = x

For the shank 60.355 cm = x_1

For the foot 91.800 cm = x_2

so that $X = \frac{(20.995 \cdot 7.165) + (60.355 \cdot 2.800) + (91.800 \cdot 1.170)}{11.135} =$

$$\frac{426.835}{11.135} =$$

X = 38.332 cm (SS in the figure).

Now the length of the thigh was 44.9; the height of the patella over the boundary between the shank and thigh may be set at 5 cm in the extended position — a value which I admittedly established not on this cadaver, but on other individuals; then we obtain 39.9 cm as the distance of the upper margin of the patella from our projection plane.

The difference between the calculated distances and those determined directly for the unknown center of gravity of the entire leg thus amounts to 1.6 cm; this is certainly within the range of individual variations, even when we assume identical dissection procedures.

For the entire arm, we have in our case the following numerical values for the calculation

$$\frac{(2{,}07 \cdot 17{,}621) + (1{,}16 \cdot 40{,}522) + (0{,}54 \cdot 75{,}9118)}{3{,}77} =$$

$$\frac{134{,}911}{3.77} = z = 35.785 \text{ Centimeter}$$

— the distance from the upper separation plane (AS in the figure).

However, the length of the upper arm measured out at 36.4. The common center of gravity of the upper extremity thus falls about one centimeter above the lower boundary of the upper arm, or in the internal condyle.*

Calculation and observation also agree at this point for the two cadavers, or as closely as may be expected.

Now we observe further that the variation of the locus of the over-all center of gravity of the body for different individuals is, relatively speaking, quite small. The way to test the correctness of the above figures as related to the static moments of the individual masses of the members will be to use them to reconstruct the

*Valentin places it "in the vicinity of the elbow joint." — Loc. cit. page 201.

entire cadaver and find where the over-all center of gravity occurs.

To simplify the calculation, I referred all weights to that of the hand as the unit and obtained the following values:

Weight of the	hand	= 1
	head	8.4352
	upper part of the torso	42.6940
	lower part of the torso	12.1450
	thigh	13.2520
	shank	5.1852
	foot	2.1667
	upper arm	3.8333
	forearm	2.1482

If we denote $P + P_1 + P_2$ by S, we may use, instead of the above equation $\frac{Px + P_1x_1 + P_2x_2}{P + P_1 + P_2} = X$

$$\frac{P}{S}x + \frac{P_1}{S}x_1 + \frac{P_2}{S}x_2 \ldots = X$$

If we denote P/S by Q, P_1/S by Q_1, etc., we obtain

$$X = Qx + Q_1x_1 + Q_2x_2 \ldots$$

or, logarithmically, Num. $(\lg Q + \lg x) + \text{Num.} (\lg Q_1 + \lg x_1) \ldots = X$.

Now we find the following logarithmic values in our case for the above parts of the body, setting the weight of the hand equal to unity:

Head	8.8525238 - 10
Upper part of torso	9.5567951
Lower part of torso	9.0008258
Upper arm	8.5100011
Forearm	8.2585030
Hand	7.9264283
Thigh	9.0487425
Shank	8.6411938
Foot	8.2622271

We use the plane tangent to the top of the head as the projection plane and obtain the following distances from it:

a)	for the center of gravity of the head	8
b)	for the center of gravity of the upper torso	43.7
c)	for the center of gravity of the lower torso	73.6
d)	for the center of gravity of the upper arm	45.2
e)	for the center of gravity of the forearm	75
f)	for the center of gravity of the hand	100.05
g)	for the center of gravity of the thigh	99
h)	for the center of gravity of the shank	137.9
i)	for the center of gravity of the foot	169.2

The logarithms of the values of Q_x will be found in the first column of the following table and their numerical values in the second; the letters refer to the same members as those listed above.

		Numbers
a)	9.7[illegible]56137-10	0,5[illegible]
b)	11.1[illegible]72765	15,7[illegible]
c)	10,[illegible]77026	7,37[illegible]
d)	10.1[illegible]51395	1,46150
	10,1[illegible]51395	1,46150
e)	10,[illegible]35643	1.36000
	10,[illegible]35643	1,36000
f)	9,9[illegible]6454	0.84459
	9,9[illegible]6454	0,84459
g)	11,0[illegible]43777	11,07550
	11,0[illegible]43777	11,07550
h)	10,7[illegible]67581	6,03610
	10,7[illegible]67581	6,03610
i)	10,[illegible]6275	3,09477
	10,[illegible]6275	3,09477

Sum: 71.43858 = X (HS in the figure)

Now, however, the distance from the top of the head to the plane touching the crests of the ilia measured out at 64.885 centimeters, so that the center of gravity as determined lay 6.55 cm below this plane. Subsequent measurements made on the pelvis of this executed [individual] showed that the distance of the promontorium (the upper anterior margin of the first sacral vertebra) was 6.4 cm. The distance of the upper rim of the second sacral vertebra was 8. Thus as regards the anatomical locus of this horizontal plane, we are in full agreement with the conclusion of Weber. Further, we obtain in our case a value of 10 centimeters for the distance of the center of gravity from the trochanteric line; as noted above, Meyer found it to be 9.5 cm. Finally, we find the distances of the over-all center of gravity referred to the total height (set equal to 1000) to be

413.05 from the top of the head
586.35 from the soles of the feet

If we now compare the corresponding distances as determined directly and listed above, we may conclude that the values that I

found for the static moments of the individual parts of the body are as accurate as any form of determination will deliver.*

To secure a more readily inspected representation of the masses and their mechanical interaction, I have converted them to spheres and calculated the radii of these spheres. Specifically, the weights of the individual parts are divided by 1.066 to determine their volumes, and the radii derived from these by the formula

$$R = 0.62035 \sqrt[3]{V}.$$

The following figures were obtained as a result:

	R in cm
For the hand	4.9453
forearm	6.3808
upper arm	7.7394
head	10.066
upper part of the torso	17.283
lower part of the torso	11.364
thigh	10.842
shank	8.559
foot	6.3990

If we draw the corresponding spheres in such a way as to form a skeleton, as may be particularly useful for purposes of demonstration, we have the unfortunate circumstance that the peripheries often extend far beyond the lateral limits of the soft parts and overlap one another. For this reason, I have taken the effort of computing the radii for plaster-of-paris spheres of corresponding weight and setting them in proportion to the mass of the hand.

Relative values of the radii referred to that of the hand mass set equal to unity appear in the first column; the second contains

*The figures given here are naturally applicable only for this particular case. Since, however, the volumes of the extremities are measurable even in living individuals and can be made weighable at least to very high accuracy with knowledge of the specific gravities of their sections, an aspect in which my investigations are still uncompleted, it will also become possible, when necessary, to find the values of the factors concerned here with a certain degree of approximation from the loci of the centers of gravity of the individual parts — which are made rather certain by similarities of form — for any other individual.

values for the radii of plaster-of-paris spheres corresponding to the actual masses, as they may be drawn at the places indicated on the lifesize skeleton or with the decimal point shifted, for a ten-fold reduction:

	R	R for corresponding plaster spheres
Hand	1	3.7979
Forearm	1.2903	4.9004
Upper arm	1.5650	5.9439
Head	2.0356	7.7311
Upper part of torso	3.4951	13.274
Lower part of torso	2.2980	8.7276
Thigh	2.1925	8.3269
Shank	1.7308	6.5735
Foot	1.2910	4.9145

If we again set the total height equal to 1000, we obtain the following distances of the center of gravity from the upper and lower boundary of each section of the body:

	Distance from upper boundary	Distance from lower boundary
Head	44.591	105.38
Upper part of torso	101.516	135.909
Lower part of torso	34.108	44.07
Thigh	121.58	138.43
Shank	89.499	158.931
Foot	67.545 (from the heel)	79.365 (from the toe)
Upper arm	102.27	108.52
Forearm	75.98	97.152
Hand	55.725	61.914

The vertical distances of the individual centers of gravity from the horizontal projection plane are determined by these calculations. It may be assumed for the trunk and head that the centers of gravity may be placed simultaneously in the plane defined by the middle of the <u>lince alba</u> [sic] and the <u>processus spinosi</u>. The location of the over-all center of gravity with reference to the third plane, which runs parallel to the median [coronal] plane of the lateral view, has been determined by Meyer's experiments, as already noted above. On the basis of his calculations, Horner* identifies

*Loc. cit.

the locus of the common center of gravity of the head and torso with the arms as the highest point on the anterior margin of the ninth thoracic vertebra, i.e., a point in the vertical constructed by Meyer, which connects the pivot axis of the upper atlas joint and the point of the coccyx in the standing position. The center of gravity of the trunk alone may probably also be placed in this line; its distance from the trochanteric line comes to

29.267 cm (RS in the figure)

according to the static moments found above for its two parts.

This corresponds approximately to the lower dorsal margin of the body of the last (twelfth) thoracic vertebra. For the extremities and their lower sections, it may be assumed that the centers of gravity lie in their structural axes.

For my part, these investigations of the static moments of the masses of our various members were undertaken for practical purposes. The locus of the over-all center of gravity changes for different attitudes in which we approximate members to one another, and with burdens which we carry simultaneously in one way or another, etc. It has hitherto been impossible to give any accurate statement regarding this change as it affects the supporting surface, i.e., the point at which the perpendicular dropped from the center of gravity (the weight vector) meets the supporting surface, since the values of the individual parallel forces were not known with sufficient accuracy. Consequently, the drawings offered by Ch. Dupin* were also based more on guesswork than scientific investigation. And indeed, nothing is of greater importance for the graphic arts than proper evaluation of these relationships. When we remember that placement

*Ch. Dupin. Geometrie et Mecanique des arts et metiers et des beaux-arts. Tome II. Tab. I.

of the center of gravity higher or lower above the supporting surface, or nearer or farther from its boundary, will produce now the effect of a confident, relaxed posture, and now that of a motion in one direction or another with one acceleration or another, since each onlooker has had a wealth of experience, from his youth on, concerning equilibrium as a subjective matter, we will realize at once that the representational artist must be familiar with these laws unless he is willing to let correct choice of attitude depend merely on uncertain groping. To make the judgements easier, I have also computed the masses of spheres that can be used to build a model – say of wire – from which the eye alone can determine the locus of the general center of gravity more easily. (cf. the accompanying table).

For the rest, there is still another way to circumvent the often rather complicated calculations for this locus without compromising very much of the mathematical accuracy.

This is done by means of an apparatus based on the balancing principle.

I shall conclude by describing this apparatus.

A flat square plate is graduated in millimeters on its four edges. A cross divides it into four equal squares. The zero points of the marginal graduation correspond to the outer ends of the cross.

A brass clamp of the appropriate dimensions and having an indicator which shifts along the edge graduation carries a metallic millimeter-graduated vertical-square scale on which a sleeve can be pushed up and down; this guides another square scale, which is similarly divided. As the former remains standing exactly vertical with the screw tightened, so the latter remains exactly parallel to the horizontal base plane. On the vertical scale, the zero point lies in the horizontal base plane; on the horizontal scale, it occurs

at the crossing point of the two lines drawn on that surface. A figure is secured at this point in such a way that the vertical constructed by Meyer strikes it [the intersection] in the standing position. By moving the point of the horizontal scale in such a way that it gradually comes up to touch the center of gravity of each individual member, we simultaneously obtain readings for the distances from the three planes for each of these points.

Now we have a second apparatus which indicates the resultants for each single plane. It consists of a beam about 5 centimeters in width and of considerable length, which is balanced on knife edges and can be arrested in the same way as a sensitive balance.

We have as many weights as there are movable centers of gravity on the figure, each having the value of the appropriate Q of our formula.

These weights have markers, so that the center of gravity of each can be moved over that graduation mark on the balance beam which corresponds to the reading for the distance of the center of gravity from the plane in question.

Thus, if all of the individual weights are at their appropriate places on one side of the balance beam, a weight smaller than the sum $Q + Q_1 \ldots$ will be pushed far enough from the fulcrum on the other half of the beam to bring it into equilibrium.

The zero point for the half of the balance beam on which the counterweight is resting lies at this point.

If we now change the attitude of the figure, and shift the weights as called for by the readings on the coordinate index, it will also be necessary to shift the counterweight on the other half of the balance beam, and the extent of this displacement will depend on the ratio of the resultant effect of this single displacement to

the difference between the absolute magnitude of the counterweight and the sum of the Q. The larger this difference is made, the greater will be the deflection and the more accurate will be the location of the over-all center of gravity after determination of the constants by which the displacement of the counterweight is to be divided.

Each such weighing determines the distance from one of the three planes; their combination determines the locus of the over-all center of gravity in space in the specific attitude into which the figure or its model has been brought.

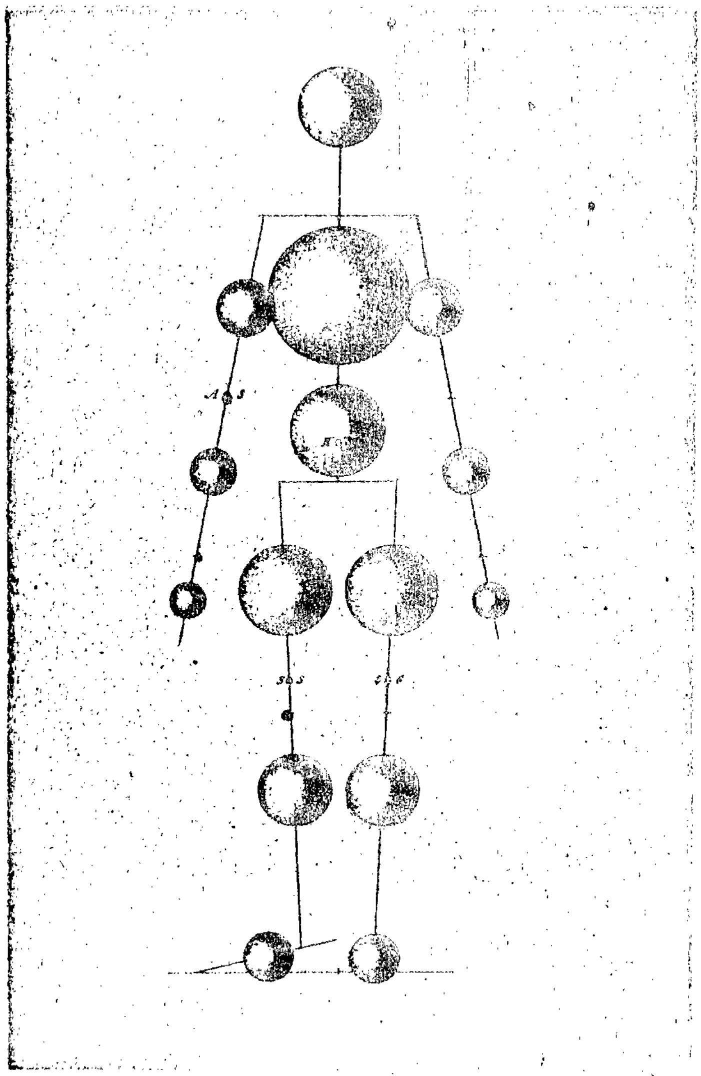

Diagram of mass distribution.

THE STATIC MOMENTS OF THE COMPONENT MASSES OF THE HUMAN BODY

Since it is only relatively seldom that we may expect to come by a whole cadaver at once in positions where, as in our institute of anatomy, there are requests from many sources for the bodies of executed persons or individual parts thereof, which are rightfully needed or, at any rate, desired for various scientific purposes, I was obliged for the time being to satisfy myself with publication, in the first report, of the problem set forth by the above title, which was resolved on a single specimen.

I have already made reference to the restriction of the figures reported there to a special case. In the meanwhile, considerable experience has convinced me that there is a much higher degree of regularity in the distribution of the masses on our organism than we should probably be inclined to suppose.

Even the minor variations in the locus of the over-all center of gravity for the same attitude in different individuals, as well as the slight differences shown by the positions of the centers of gravity of entire extremities, as noted in the first report, were alone sufficient to suggest this.

It is a fact that the superficial phenomena of movements made by an individual human would have to show a much wider and more conspicuous variety than is actually the case if the arrangement of the masses, the lever-arm ratios, and the relative weights of the parts, as well as the loci of the centers of gravity were subject to large variations.

This, however, is not the case.

I shall first communicate measurements and calculations for the corpse of one 29-year-old Kefer, who was executed in January 1857, which, again, Herr Prof. Bischoff was kind enough to turn over to me for this purpose, and use them to argue the method already illuminated in the "Gelehrte Anzeigen," by which it is also possible to set up the critical observations for this work in any other case, including that of the living individual.

A practical evaluation of the results obtained here — which were, indeed, the very reason for which the entire investigation was undertaken — will be found in Volume III of my "Lehrbuch der plastischen Anatomie" (Textbook of Plastic Anatomy).

I.

Dismemberment, measurement, and weighing, as well as determination of the loci of the centers of gravity of all of the individual members, were carried out following the procedures already reported in the first report. This time, I did not rest content with average values for two like extremities, but based the calculations on individual measurements for each piece; further, the individual measurements were made with still more highly perfected instruments and checked by several persons, as were the weighings and equilibriation experiments.

The results of the measurements were as follows:

Total height of the body		167.7 cm
Height of head		20.2 cm
Height of foot		9.7 cm
Length of shank		38.15 cm
Length of thigh		42.3 cm
	Total	90.15 cm

The length of the trunk was obtained from three different meas-

urements, in part for the whole piece and in part for the sum of its individual sections, and came, accordingly, to 57.5 cm.

From this we obtain for the total height

for the head	20.2 cm
for the trunk	57.5 cm
for the lower extremities	90.15 cm
Total	167.85 cm

Special measurements made on the individual sections of the extremities, with the most accurate possible consideration of the straight-line distances between the pivot points of their individual joints, gave the following values:

for the thigh	right 42.3 cm	left 42.3 cm
for the shank	right 38 cm	left 38.1 cm
for the total length of the foot	right 25 cm	left 25 cm
for the foot from the pivot point of the talus to the midpoint of the capitulum of the first metatarsal (oblique line)	right 14.1 cm	left 14.1 cm
for the width of the foot at the heel	6.3 cm	
for the width of the foot at the ball	9.9 cm	
for the length of the upper arm	right 30.6 cm	left 30 cm
for the forearm	right 26.4 cm	left 26.1 cm
for the hand	right 18.5 cm	left 18.9 cm

I note here in passing that useful determinations of the pivot points of individual joints for extremely accurate measurements can also be obtained on living individuals by the following procedure. One half of the joint, e.g., the shoulder girdle is immobilized by some sort of bracing or bandaging appliance. Photographs are then made as follows. An exposure time somewhat longer than usual is divided into three equal parts. At the end of each of these periods, the joint is moved as rapidly as possible to a new position and held there throughout the next period. Thus we obtain, in <u>one</u> picture,

three different positions, each very sharply defined, provided that we have followed the simple rule of thumb not to overexpose the background behind the part being moved either before or after the part is moved in front of it. If, for example, the arm is interposed in front of the trunk or some other part of the body in the last period, that part remains draped prior to this period by a dark red sheet, which is quickly whisked away immediately before this period begins. For the same reason, it is not admissible to have the moved part in front of some other surface of the body at the start of photography, since the modeling of its bright image would be effaced in the subsequent periods of the process.

In this way, we obtain the appropriate number of points for construction of the ligaments and their corresponding arcs of movement, and for determination of the pivot points.

Measurements on the cadaver's torso gave the following results:

Distance between the two peaks of the cristae oss. ilium	27.1 cm
Breadth of the lower end of the thorax	27.7 cm
Outside breadth of the pelvic floor after exarticulation of the femora	10.2 cm
Diameter of the largest circle on the caput femoris	right 4.9 left 4.8 cm
Diameter of largest circle on the caput humeri	right and left 4.4 cm
Distance between pivot points of shoulder joints	29.9 cm
Distance between pivot points of hip hoints	16.8 cm
Depth of trunk from manubrium sterni to vertebral column	14.5 cm
At middle level of shoulder blades	17.5 cm
At the level of the processus xyphoideus	19.1 cm
At the level of the mons pubis	16.9 cm

If we set the total height equal to 1000, the relative values of these measurements will be drawn up as follows:

Height of head	120
Height of torso	343
Length of lower extremities	537
	1000

Length of thigh	252
Length of shank	227
Height of foot	58
	537

Length of foot	149.07
Length of right upper extremity	450.207
Length of its upper arm	182.465
Length oɪ forearm	157.425
Length of hand	110.317
Length of left upper extremity	447.226
Length of its upper arm	178.893
Length of its forearm	155.63
Length of its hand	112.703

The relative measurements for the torso were computed in the following manner:

Distance between two peaks of cristae ossis ilium	161.6
Breadth of lower end of thorax	165.175
Outside transverse diameter of pelvic floor	60.823
Diameter of largest circle on caput femoris right side	29.219
left side	28.623
Diameter of largest circle on caput humeri either side	26.237
Distance between pivot points of two shoulder joints	178.3
Distance between pivot points of two hip joints	100.177
Depth of thorax at level of manubrium sterni	86.463
Depth of thorax at middle level of shoulder blades	104.355
Depth of torso at level of xyphoid process	113.89
Depth of torso at level of mons pubis	100.775

If we regard the length measurements as multiples of the hand length, as was done in the first report, we obtain the following list:

right hand	= 1
head	1.09
entire trunk	3.105
lower extremity	4.87
entire body	9.065

upper part of torso	2.16
lower part of torso	0.945
thigh	2.29
shank	2.06
height of foot	0.52
total length of foot	1.351
entire upper extremity, right side	= 4.081
its upper arm	= 1.654
its forearm	= 1.427
its hand	= 1
entire upper extremity, left side	= 4.0540
its upper arm	= 1.6216
its forearm	= 1.4108
its hand	= 1.0216

As regards determination of the weight of the entire body, it is to be regretted that we were not permitted to weigh it before execution. The corpse weighed 47,087 grams.

The head alone weighed	3,747 grams;
the remainder weighed	43,340 grams.

The amount of blood that Kefer had lost at his execution may be calculated approximately from the percentage represented by the blood lost by Graf on a similar occasion. For [Kefer's] remains, this was accordingly

2808 grams.

Added to the above figures, this gives for the weight before execution

49,895 grams.

After the four extremities had been exarticulated, the bloodless torso weighed

19,846.5 grams.

The extremities and the head had a total weight of

27,240.4 grams;

subtracted from the total weight of the body (49,895 grams), these leave for the headless and limbless torso a weight of

22,654.6 grams;

on subtraction of this from the 19,846.5 grams determined with the balance, this leaves 2.808 kilograms as the amount of blood that had escaped the trunk.

The weights of the individual sections of the extremities after removal at exactly the same sections (insofar as this is at all possible) followed in dissecting Graf's remains were as follows:

entire right lower extremity	9171.8 grams
entire left lower extremity	9067.6 "
right thigh	5947 "
left thigh	5827 "
right shank	2242.6 "

left shank	2252.4	grams
right foot	982.2	"
left foot	988.2	"
right upper arm	1484.5	"
left upper arm	1411.3	"
right forearm	821.1	"
left forearm	770.1	"
right hand	393.2	"
left hand	374	"
entire right upper extremity	2698.7	"
entire left upper extremity	2555.4	"

The procedure for splitting the trunk into two parts, even though these were not anatomically separable with perfect distinctness, was also followed in this case with the object of computing their masses, but the formulas for vessels with dissimilar elliptical base surfaces were used instead of those for determining the volume of a truncated cone. At any rate, the latter corresponds more exactly to the given shape relationships of the trunk.

As we know, this formula for calculating the volumes of vessels with such elliptical base surfaces is

$$V = \frac{\pi h}{6} [2 \ (ab + a_1 b_1) + ab_1 + a_1 b]$$

where a and b are the semimajor axes, a_1 and b_1 are the semiminor axes, and h is the height.

For the upper torso of the cadaver,

$$a = 14.9 \text{ cm}$$
$$b = 8 \text{ "}$$
$$a_1 = 13.55 \text{ "}$$
$$b_1 = 9.15 \text{ "}$$
$$h = 40 \text{ "}$$

This gave the volume V as 15,310.5 cubic centimeters; multiplied by 1.066, this corresponds to a weight of

16.3225 kg

for the upper torso.

According to the same formula, the weight of the lower torso,

computed for the axes	13.55 cm
	8.45 cm
	6.75 cm
	6 cm

and a value of 1.75 for h, came to

4.38 kilograms.

Accordingly, the weight of the entire trunk was

$$16.3225 + 4.38 = 20.7025 \text{ kilograms.}$$

According to the above calculations, however, its weight was

22.6546 kilograms.

This represents a deficit of 1.952 kilograms, which can be distributed in accordance with the weight ratio of the two parts in such a way that the weight of the upper trunk may be assumed equal to 17,776.6 grams and that of the lower trunk to 4868 grams.

In relation to the weight of the right hand, with the latter set equal to unity, all these parts of the body acquire the following weight values:

Entire body	126.9
Head	9.5295
Upper trunk	45.209
Lower trunk	12.3805
Right upper arm	3.77545
Left upper arm	3.58925
Right forearm	2.0875
Left forearm	1.9583
Left hand	0.95117
Right hand	1.0
Right thigh	15.1245
Left thigh	14.8195
Right shank	5.70345
Left shank	5.72834
Right foot	2.49795
Left foot	2.51325

In addition to the weight proportions we have yet to give the loci of the center of gravity in each individual part.

With the exception of the torso, these loci were determined experimentally by the procedure outlined in the first report.

For the head, it lies 7.3 cm from the crown.

For the right thigh, 18.2 cm from the midpoint of the caput femoris; for the left thigh, 17.7 cm.

For the right and left shanks, 21.15 cm from the middle of the malleolus externus.

For the right and left feet, 10.9 cm from the heel.

For the right and left upper arms, 12.95 cm from the midpoint of the caput humeri.

For the right and left forearms, respectively, 10.7 and 11.05 from the elbow-joint pivot point.

For the right and left hands, 6.75 from the pivot axis of the carpus.

For the upper and lower parts of the trunk, the positions of the center of gravity were computed by the formulas given in the first report, and were found to occur at

20.116 cm from the lower boundary

of the 40-cm-high upper torso and

9.0605 cm from the upper boundary

of the 17.5-cm-high lower torso.

The distances of all these individual centers of gravity from the plane of the top of the head were thus

For the head	7.3	cm
for the upper torso	46.384	"
for the lower torso	69.2605	"
for the right upper arm	39.45	"
for the left upper arm	39.45	"
for the right forearm	67.8	"
for the left forearm	67.55	"
for the right hand	102	"
for the left hand	101.5	"
for the right thigh	95.9	"
for the left thigh	95.4	"
for both shanks	141.15	"
for both feet	163.5	"

If we again set up the relationships of the distances from the the boundaries of the individual parts on the one hand, with the

length of each member assumed equal to unity, and, on the other, the distances of the various centers of gravity as fractions of the total height of the body, which is set equal to 1000, we obtain the following picture:

DISTANCES OF THE INDIVIDUAL CENTERS OF GRAVITY

	From the upper boundary of each member, the length of which is set equal to 1	From the lower boundary of each member, the length of which is set equal to 1	From the plane of the top of the head, whose distance from the soles of the feet is set equal to 1000.
Head	0.3613	0.6387	43.5305
Upper torso	0.4971	0.5029	276.585
Lower torso	0.51774	0.48226	413.0
Right upper arm	0.42739	0.57261	235.245
Left upper arm	0.4316	0.5684	235.245
Right forearm	0.41758	0.58242	404.29
Left forearm	0.4023	0.5977	402.805
Right hand	0.361	0.639	608.23
Left hand	0.3571	0.6429	605.245
Right thigh	0.4302	0.4184	571.85
Left thigh	0.5698	0.5816	568.875
Right shank	0.4435	0.5565	841.68
Left shank	0.4945	0.5055	841.68
Right foot	0.436	0.564	974.955
	(From the heel)	(From the toe)	
Left foot	0.436	0.564	974.955
Average	0.4322	0.5678	

As a check on the correctness of the measurements and calculations, we must resort to the formula for the locus of the center of gravity of the entire body, as derived on page 17 (first report).

For the corpse of Kefer, the logarithms of Q for each formula were as follows:

		Numbers
Head	8.8756086	0.0750945
Upper torso	9.5517712	0.356265
Lower torso	8.9892755	0.097560
Right upper arm	8.4735051	0.0297516
Left upper arm	8.4515442	0.0282845
Right forearm	8.2162681	0.0164535
Left forearm	8.1884156	0.0154315
Right hand	7.8965384	0.0078802
Left hand	7.8747965	0.0074954
Right thigh	9.0762228	0.119185
Left thigh	9.0673699	0.116783

		Numbers
Right shank	8.6526767	0.0449445
Left shank	8.6545704	0.0451406
Right foot	8.2941248	0.0196845
Left foot	8.2967697	0.0193046

Then the X of each formula is computed from the sum of the Qx, the values of which are as follows:

Head	0.54819
Upper torso	16.5245
Lower torso	6.7571
Right upper arm	1.17367
Left upper arm	1.11585
Right forearm	1.1156
Left forearm	1.04245
Right hand	0.803783
Left hand	0.760784
Right thigh	11.4297
Left thigh	11.1406
Right shank	6.34395
Left shank	6.37167
Right foot	3.21845
Left foot	3.23805
Sum =	71.584347 = X

However, this distance of the over-all center of gravity of the body, whose total height has been set equal to 1000, is

426.85 from the top of the head,

a figure which agrees as closely as possible with the average of 420.07 given in the first report (page 5), when we remember how many calculations – not all of them absolutely accurate – must ultimately contribute to the acquisition of this single figure.

That average value applies only for adult males. It is understandable that the corresponding figure for the female sex will be different as a result of the differences in their physical configuration, and that the locus of the over-all center of gravity will change in the various earlier phases of life.

I present here – as preliminary data – certain determinations for the female sex, which show considerably greater scattering, without attempting to derive a general law for them at this time.

	Height of body in cm	Distance of center of gravity from the top of the head in cm	Distance of center of gravity from top of head for total height of 1000
I. Age 31 years (nonparous; extremely robust build)	160.5	71	442.3
II. 19 years old (uniparous, well-proportioned)	157	70.7	450.3
III. 24 years old (uniparous, slight build)	167.4	73.15	436.9

In all cases, the center of gravity in the fully extended reclining position falls in the region of the sacrum. In children, e.g., in the case of a 6 3/4-year-old girl, in whom the distance of the center of gravity from the top of the head was 422.07, it lies in the plane tangent to the iliac crests; in another, at 425.2 cm from the top of the head, or 1/2 centimeter above this plane. This is noted only in passing; let us proceed now to consideration of the table on pages 38 and 39.

This table, which assembles for inspection all of the figures obtained for the cadavers of Graf and Kefer, shows how virtually free compensation produces identical loci for the center of gravity. Specifically, we may consider the differences after the xQ column as the sum of two products, one of which is formed by x∆Q and the other by Q∆x. Comparison of the figures thus formed with one another shows how the high degree of similarity in the positions of the two over-all centers of gravity was arrived at in the two cases under consideration. In the case of Kefer, however, using the values of x and Q for Graf, we obtain the following series:

	x∆Q	Q∆x
Head	+0.03	-0.05
Upper torso	-0.182	+0.967
Lower torso	-0.365	-0.444
Upper arm	-0.118	-0.186
Forearm	-0.164	-0.132

	$x\Delta Q$	$Q\Delta x$
Hand	-0.0755	+0.0143
Thigh	+0.610	-0.375
Shank	+0.18	+0.14
Foot	+0.235	-0.1043

This simultaneously confers a certain value on the instrument known as the "mechanical seesaw," which I mentioned in the first report and described in detail in the "Gelehrte Anzeigen,"* in that the weights used with it can be used directly, at least for all well-formed male specimens, without any appreciable error.

I have made frequent tests of the instrument's resolution and, for example, was obliged to set the counterweight at 71.25 after setting the weights for the distances of the individual centers of gravity from the plane of the top of the head in the case of Graf. The difference between the result of the logarithmic calculation and the reading on the instrument came to only 0.1%.

I have also run various experiments with the instrument using various living models and statuary and, for example, obtained for the famous statuette of Mercury, which found its way from Ch. Dupin's workshop to Valentin's testbook, a reading in full agreement with the principles developed by Meyer, and, as it turned out, with calculation as well. The weight vector is drawn at the designated point** in such a way as to drop straight through the tip of the toe. The standing position is no longer possible in this case. However, observations made with my instrument and calculation from the positions of all the individual members indicated that the artist had judged the proper equilibrium with almost unbelievable delicacy; the true weight vector drops directly behind the ball of the great toe (pivot axis of first capitulum metatarsi); the figure can balance in this position.

*The instrument is available on order from Mechanic Stollenreuther in Munich; its price is 36 fl.

**Valentin, Lehrbuch der Physiologie des Menschen, Vol. I, 3114.

1) Namen der Theile	2) Absolute Gewichte 3) Graf	2) Absolute Gewichte 4) Kefer	5) Differenz	6) Relative Gewichte (Hand = 1) 3) Graf	6) Relative Gewichte (Hand = 1) 4) Kefer	5) Differenz	7) Absolute Längenmasse 3) Graf	7) Absolute Längenmasse 4) Kefer	Differenz	8) Relative Längenmasse 3) Graf	8) Relative Längenmasse 4) Kefer	5) Differenz
	13) [illegible]						14) [illegible]					
15) Kopf	[illegible]	2747	− [illegible]	[illegible]	[illegible]	−1.0[illegible]	21.2	[illegible]	−1.0	122.7	120	[illegible]
16) Oberrumpf	[illegible]	[illegible]	−5278.1	[illegible]	15.2[illegible]	−2.519	41	40	−1	235.82	228.[illegible]	−12.[illegible]
17) Unterrumpf	[illegible]	[illegible]	−1[illegible]5	12.8[illegible]	12.3[illegible]	[illegible]0.2255	13.5	17.5	+4.0	81.1	[illegible]	[illegible]
18) r. Oberarm 19) l. Oberarm	2076	1283.5 1447.9 (Mittel) 1613	−622.1	3.8533	3.77[illegible] 3.[illegible] (M.) 3.[illegible]	−0.15[illegible]	36.6	30.6 30.3 (M.) 30	−6.3	211.66	182.[illegible] 180.[illegible] (M.) 178.[illegible]	−30.[illegible]
20) r. Vorderarm 21) l. Vorderarm	1144	821 7[illegible] (M.) 770.1	−36[illegible]	2.1[illegible]	2.0[illegible] [illegible] (M.) 1.95[illegible]	−0.1232	29.[illegible]	26.4 26.25 (M.) 26.1	−3.62[illegible]	173.07	157.[illegible] 15[illegible] (M.) 15[illegible]	−16.[illegible]
22) r. Hand 23) l. Hand	5[illegible]	3[illegible] 3[illegible] (M.) 37[illegible]	−156.4	1	1 [illegible] 0.95117		20.3[illegible]	18.5 18.7 (M.) 18.9	−1.61[illegible]	117.62	110.317 111.51 (M.) 112.703	−6.11
24) r. Oberschenkel 25) l. Oberschenkel	71[illegible]	5917 5[illegible] (M.) [illegible]	−127[illegible]	13.222	15.12[illegible] 1[illegible] (M.) 14.[illegible]	+[illegible].720	65.2	62.3 62.3	−2.[illegible]	270.90	252	−7.[illegible]
26) r. Unterschenkel 27) l. Unterschenkel	25[illegible]	2212.6 2217.5 (M.) 2222.4	−332.5	[illegible]	5.70[illegible] 5.71[illegible] (M.) 5.72[illegible]	+0.[illegible]	52.0	[illegible] [illegible] (M.) 26.1	−5.[illegible]	2[illegible].105	227	21.6[illegible]
28) r. Fuss 29) l. Fuss	117[illegible]	9[illegible]2 9[illegible] (M.) 9[illegible]2	−1[illegible]	2.[illegible]	2.[illegible] 2.[illegible] (M.) 2.[illegible]	[illegible]	8	9.7 9.7	+3.7	34.74	38	+[illegible]
ganzer Körper	[illegible]	[illegible]	1[illegible]75	[illegible]	1[illegible]	[illegible]	172.6[illegible]	167.7	−4.95[illegible]	1000	1000	

9) Relative Längenmasse (Hand = 1) Graf	9) Relative Längenmasse (Hand = 1) Kefer	5) Differenz	10) Abstände von der Scheitellinie bei dem Totalbau Graf	10) Abstände von der Scheitellinie bei dem Totalbau Kefer	5) Differenz	11) Werthe von Q Graf	11) Werthe von Q Kefer	5) Differenz	12) Werthe von XQ Graf	12) Werthe von XQ Kefer	5) Differenz
1.0[illegible]	[illegible]	+0.0[illegible]	16.3[illegible]	[illegible]	−2.7[illegible]	0.07[illegible]	[illegible]	+0.0[illegible]	0.5[illegible]	0.5[illegible]	[illegible]
1.9	2.1[illegible]	+0.26	2[illegible]	276.[illegible]	+2[illegible]	0.[illegible]	[illegible]	−0.004175	15.7500	16.[illegible]	[illegible]
[illegible]	[illegible]	+0.2[illegible]	126.16	113.0	13.16	[illegible]	[illegible]	−0.00[illegible]7	7.5[illegible]	6.7[illegible]	−0.7[illegible]
1.7[illegible]	1.6[illegible] 1.[illegible] (M.) 1.6216	−0.15[illegible]	261.72	2[illegible]	2[illegible]	0.0[illegible] 0.0[illegible]	0.0[illegible] 0.0[illegible] (M.) 0.0[illegible]	−0.0026104	1.4615	1.17[illegible] 1.1[illegible] (M.) 1.1[illegible]	−0.3[illegible]
1.471	1.427 1.4[illegible] (M.) 1.[illegible]	−0.0[illegible]	13[illegible]	40[illegible] 40[illegible] (M.) [illegible]	−30.753	0.0[illegible]	0.0[illegible] 0.0[illegible] (M.) 0.0[illegible]	−0.002[illegible]	1.5[illegible]	1.1[illegible] 1.0[illegible] (M.) 1.0[illegible]	−0.2[illegible]
1	1 1.0216		579.32	60[illegible].25 60[illegible] (M.) 60[illegible]	+27.[illegible]	0.00[illegible]	0.0[illegible] 0.0[illegible] (M.) 0.0[illegible]	−0.000[illegible]	0.[illegible]	0.[illegible] 0.7[illegible] (M.) 0.7[illegible]	−0.0[illegible]
2.2102	2.29	+0.07[illegible]	3[illegible]	571.[illegible] 57[illegible] (M.) 5[illegible]	−2.[illegible]	0.1[illegible]	0.11[illegible] 0.11[illegible] (M.) 0.116[illegible]	−0.00[illegible]	11.07[illegible]	11.[illegible] 11.2[illegible] (M.) 11.[illegible]	−0.2[illegible]
2.[illegible]	2.06	−0.0[illegible]	79[illegible]	[illegible] [illegible]	+[illegible]	0.0[illegible]	0.0[illegible] 0.0[illegible] (M.) 0.0[illegible]	−0.00[illegible]	6.[illegible]	6.[illegible] 6.3[illegible] (M.) 6.37[illegible]	−0.2171
[illegible]	0.[illegible]	+0.2[illegible]	[illegible]	97[illegible] 97[illegible]	−[illegible]	[illegible]	0.0[illegible] [illegible]	−0.00[illegible]	3.[illegible]	3.2[illegible] 3.2[illegible] (M.) 3.2[illegible]	−[illegible]
[illegible]	[illegible]	+0.[illegible]						31) Summe	71.[illegible]	71.[illegible]	32) 1.[illegible] Tabelle [illegible]

1) Name of part; 2) absolute weights; 3) Graf; 4) Kefer; 5) difference; 6) relative weights (hand = 1); 7) absolute length measurements; 8) relative length measurements (total height = 1000); [Key to Table cont'd. on page 39]

[Key to Table cont'd. from page 38]

9) relative length measurements (hand = 1); 10) distance from plane of top of head for total height of 1000; 11) values of Q; 12) values of xQ; 13) grams; 14) centimeters; 15) head; 16) upper torso; 17) lower torso; 18) right upper arm; 19) left upper arm; 20) right forearm; 21) left forearm; 22) right hand; 23) left hand; 24) right thigh; 25) left thigh; 26) right shank; 27) left shank; 28) right foot; 29) left foot; 30) entire body; 31) sum; 32) 1.37% of the total height, [about 7''' (poor legibility – Trans.)]; M) average.

Since, as a result of these investigations, together with that which has been established by different observers for different individuals with regard to the locus of the center of gravity of the reclining human body and its larger combined component masses, as summarized in the first report, it now seems justifiable to assume a major degree of harmony in the interaction of the static moments of all the individual component masses, a way remains open for each exact investigation (exact to the extent possible here) of a specific case, even in investigations being carried out on living individuals, for determining all of the figures required to find the position of the over-all center of gravity from its components in the various positions.

This is the second part of the problem which I have undertaken in this study, and I pass without further ado to its solution.

II.

The task consists primarily in finding ways that will place us in a position to weigh the parts of a living human being individually. This can obviously not be done directly; the values can only be found by calculation on the basis of knowledge of two things: firstly, the volume, and secondly, the specific gravity of the part.

It is easy to find the volume, as we shall eventually demonstrate. The first question is: can the specific gravity of such a part be determined with sufficient accuracy for each specific case?

The possibility will seem hardly conceivable to the reader, as it did to me at first, when we consider that substances of highly divergent specific gravities are combined in each part and in each individual in a wide variety of ways. Muscles, which are of nearly the same specific gravity as blood, bone, which is heavier than blood, fat, which is lighter than blood, and even lighter than water, not to mention the other tissue masses of differing specific gravity that are also interwoven with them in unequal proportions.

I nevertheless became convinced by forty-four weighings of pieces of extremities from a wide variety of adult corpses that as great a degree of harmonization through mutual compensation of the mass distribution also prevails in this respect as that which became evident in a similar conspicuous manner in connection with the static moments.

Since the problem of finding the latter had been formulated first, I made the cuts by which the members were separated one from another in the same way as described in the first report.

The weighings in air were set up on a high-precision balance of the design of Mechanic Ungerer of this place; then the members were weighed in water, following the principle of Archimedes, with the temperature and specific gravity of the water checked as accurately as possible before and after each weighing.

This made it possible to use the familiar method to compute the specific W[illegible] ~~gravity~~ of each part by comparison with ~~that of~~ distilled water of maximum density, and to find its volume as well.

I first submit the results of the investigations made on the single cadavers in the order in which they were carried out.

I. Corpse of an emaciated 68-year-old man who had died of marasmus senilis:

Part	Right side Weights absolute grams	specific	Left side Weights absolute grams	specific
Upper arm	1420.7	1.09036	1239.1	1.0936
Forearm	767.2	1.111905	765.3	1.111725
Hand	447.7	1.1093	443.9	1.1034
Thigh	4670	1.08705	4460.4	1.08715
Shank	1874	1.1265	1811	1.1295
Foot	952.5	1.0950	965.5	1.09975

The extent of emaciation or, more generally, the predominance of bony substance, is manifested in this case through the higher value of the specific gravity shown by the forearm as opposed to the hand; this relationship is exactly the opposite in younger specimens. Young and healthy persons and persons who have died suddenly also have feet that are specifically lighter than the lower leg, as will be shown later. Nor will the observation that pieces of the left lower extremity have higher absolute weights than the corresponding pieces of the right extremity remain an isolated one.

II. Corpse of a 26-year-old woman, well-nourished and rather obese:

Part	Right side Weights absolute grams	specific	Left side Weights absolute grams	specific
Thigh	4890	1.0532	4723	1.0514
Shank	1947.9	1.0773	1863.15	1.0785
Foot	755.05	1.1017	713.45	1.0996

III. Corpse of the extremely robust murdered highway robber Heigel, age 40 years.

Part	Right side Weights absolute grams	specific	Left side Weights absolute grams	specific
Upper arm	2560.1	1.08375		
Forearm	1389.7	1.10295		
Hand	525.1	1.11336		
Thigh	7567.0	1.06586	7367.0	1.0598
Shank	2760.2	1.0859	2806.9	1.08607
Foot	1038.8	1.08015	1072.3	1.07668

IV. Corpse of a very slender girl of 20 years:

Part	Right side Weights absolute grams	specific
Upper arm	1525.6	1.0622
Forearm	725.6	1.0804
Hand	316.8	1.1163

V. Body of the executed criminal Kefer, age 29 years:

Part	Right side Weights absolute grams	specific	Left side Weights absolute grams	specific
Upper arm	1484.5	1.0872	1411.3	1.0884
Forearm	821	1.1091	770.1	1.1127
Hand	393.2	1.1191	374	1.1178
Thigh	5947	1.0549	5827	1.0564
Shank	2242.6	1.0861	2252.4	1.0861
Foot	982.2	1.0924	988.2	1.0916
Head	absolute grams - 3747, specific - 1.0851			

VI. Head of the executed 38-year-old Pickel:

absolute in grams - 4980, specific - 1.1300

If we compute the averages of the specific gravities for the individual parts of these corpses, which differ so greatly as regards age and constitution, and list them all together, we obtain the following results:

1) Name des Theils	2) Mann 68 J.	3) Weib 26 J.	4) Mann 40 J.	5) Mädchen 20 J.	6) Mann 29 J.	7) Mittel
9) Oberarm	1,09198	1,05705	1,08375	1,0622	1,0882	1,08117
10) Vorderarm	1,11845	1,09244	1,10295	1,0804	1,1113	1,10035
11) Hand	1,10635	1,1097	1,11336	1,1163	1,1184	1,11511
12) Oberschenkel	1,087105	1,0523	1,06253		1,0556	1,062551
13) Unterschenkel	1,1280	1,0779	1,06598		1,0865	1,067425
14) Fuss	1,093375	1,10053	1,07341	8) Frau 38 J. alt	1,0924	1,095605
15) Kopf				1,1300	1,0851	1,1075

1) Name of part; 2) 68-year-old man; 3) 26-year-old woman; 4) 40-year-old man; 5) 20-year-old girl; 6) 29-year-old man; 7) average; 8) 38-year-old woman; 9) upper arm; 10) forearm; 11) hand; 12) thigh; 13) shank; 14) foot; 15) head.

If we arrange the individual parts in order of increasing specific gravity, we obtain the following series for the average:

Thigh
Upper arm
Foot
Shank
Forearm
Head
Hand

There is nothing remarkable about the fact that the parts most abundantly provided with soft tissues, flesh, and fat stand at one end of the list, while the hand, the tissues of which are composed for the most part of bones and sinews, stands at the other end. We should certainly have supposed, however, that the foot would appear nearer the hand in this series. Either the large spongy bones of its tarsus are very rich in fat or the fatty cushion on the sole is the cause of an unexpected depression of the specific gravity of the entire foot.

On the whole, however, the differences between the specific gravities of all these parts are very small; nor does it make such a great difference if a member, as, for example, the thigh, is heavy, whether this is due to well-developed musculature or more to fat, even though this difference is expressed in the small differences to be noted above.

The largest difference of all those found here is 0.0339. While the absolute weights in the extreme cases are in the ratio of 1:24, the ratio 1:1.03 applies for the specific gravities.

The tabular summary given below, in which the volumes are listed in ascending order, provides a survey of these large differences on the one hand and these small differences on the other.

We have still overlooked the possibility of abstracting some value of the specific gravity for a given part of the body from the column and using it to compute the absolute weight without incurring any appreciable error. Moreover, this error can be still further minimized.

To accomplish this, however, it becomes necessary to outline a method by which it is possible to find the volume of a member for a living individual; for this is the second quantity to be found by

observation before computation of the weight will be possible.

For the sections of the extremities, I use tall, narrow galvalized-sheet cylinders having cross sections exceeding the largest cross sections of the parts for which they are intended by the smallest possible margin; for the entire body, I employ a tall barrel. One-half inch from their upper rims, the cylinders have a short, curved trough-shaped pour spout. They are filled with water at a known temperature and density until overflow at the brim stops. Needless to say, they are positioned perfectly securely and vertically.

A calibrated glass flask is set up under the spout and, e.g., the hand of the individual to be investigated is slowly immersed into the cylinder after preliminary determination of the wrist-joint pivot-axis bounaries. When this axis lies in the same plane as the base of the trough and no further water is running into the flask, the hand is drawn out; the water clinging to it is allowed to drip off into the cylinder while the flask, which had previously contained a known amount of water, is being weighed.

When the newly added water that has been displaced by the hand is weighed, water is added cautiously at the brim of the cylinder until the first excess drop flows out of the trough.

Now the flask is reweighed, and the loss in weight now gives another observation for the amount of water displaced by the hand. Both observations carry errors of opposite signs. In the first case, it is inevitable that the amount of water that flows out is somewhat larger than that actually displaced by the form of the member because of small muscular movements and ripplings in the water; in the second case, the first droplet is almost as inevitably premature because of the agitation produced in pouring in the water. Thus we

obtain a small plus on the one hand and a small minus on the other. The average of the two is therefore liable to extremely small error.

We proceed in this manner, first immersing the arm up to the elbow and finally up to the shoulder, weighing the displaced quantity of water each time and ultimately checking their sum by determining the amount of water displaced by the entire extremity at once.

In order to find the volume with high accurary from the weight determinations made on the water, it is necessary to have determined the water temperature exactly in each case.

If this has been done, and if the volumes are reduced to distilled water of maximum density, it becomes a matter of determining the absolute weight of the corresponding part.

While the influence of the soft parts with their varying relative contributions to the specific gravity of the individual part are not, as we saw above, particularly large, they are nevertheless noticeable enough to merit being taken into account. As was shown by Werthheim,* the specific gravity of the bones does not remain so constant with respect to age that considerable differences in their volumes are not distinctly manifested after a certain point. The influence of the soft parts on the specific gravity of an entire member depends essentially on their mass, i.e., on the volume of the whole. If we have now become familiar as a result of weight determinations with a sufficiently large number of parts of the body having different cubic contents, the volume of the displaced mass of water in subsequent experiments made on living persons by the above method will always coincide closely now with that of the corresponding piece of one of the cadavers investigated and now with that of the same piece of another cadaver.

*Ann. ch. phys. XXI. 385.

The specific gravity of the similar part whose volume falls nearest to the amount of water displaced in a particular case can then be used with maximum confidence to calculate the absolute weight for the part under investigation.

For this purpose, it was necessary to use the absolute weights of those parts of the cadavers to determine the volumes; this gave the following series, in which these volumes are arranged in order of increasing magnitude. To aid in direct application of this table, the specific and absolute weights are repeated in it.

For proper understanding of the symbols, it is noted in advance that M stands for man, W for woman, the numerals following these letters represent the age, r and l mean left and right, H denotes the hand, VA the forearm, OS the thigh, [F = foot; US = shank; K = = head; OA = upper arm], etc.

	Volum in C. Centm. 1)	Spezifisches Gewicht 2)	Absolutes Gewicht in Gramm. 3)
W. 20. H. r.	283.795	1.1163	316.5
M. 30. H. l.	334,585	1.1179	374
M. 30. H. r.	354.35	1.1191	39[illegible].2
M. 68. H. l.	402.30	1.1034	443.9
M. 68. H. r.	403.585	1.1093	447.7
M. 40. H. r.	471.627	1.11336	525.1
W. 26. F. l.	648.825	1.0996	713.45
W. 20. VA. r.	671.605	1.0804	725,6
W. 26. F. r.	685.35	1.1017	755.05
M. 68. VA. l.	688.865	1.111725	765.3
M. 68. VA. r.	689.59	1.1119	767,2
M. 30. VA. l.	692.405	1.1127	770.4
M. 30. VA. r.	740.24	1.1001	[illegible]
M. 68. F. r.	878.865	1.085	952.5
M. 68. F. l.	887.625	1.09975	975.5
M. 30. F. r.	899.115	1.0922	982.2
M. 30. F. l.	905.275	1.0916	988.2
M. 40. F. r.	961.715	1.0[illegible]15	10[illegible],5
M. 40. F. l.	995.91	1.07669	1072.3
M. 68. OA. l.	1133.05	1.0936	1239.1
*M. 40. VA. r.	1260.0	1.10295	1389.7
M. 30. OA. l.	1296.65	1.06[illegible]	[illegible]
M. 65. OA. r.	1302.95	1.09836	1429.7
M. 30. OA. l.	1365.45	1.0872	1484.5
W. 20. OA. r.	1436.25	1.0622	1525.6

	Volum in cc Centim 1)	Specifisches Gewicht 2)	Absolutes Gewicht in Gramm. 3)
M. 68. US. l.	1603,35	1.1295	1811
M. 68. US. r.	1663,55	1.1265	1874 †
W. 26. US. l.	1727,55	1.0785	1863.15
W. 26. US. r.	1808,15	1.0773	1947.9
M. 30 US. r.	2064,85	1,0861	2242.6
M. 30. US. l	2073,85	1,0861	2252.4
*M. 40. OA. r.	2362.25	1,08475	[illegible]
M. 40 US. r.	2541,85	1,0859	2760,2
M. 40. US. l.	[illegible]	1,08607	[illegible]
M. 30. K.	3453,365	1,0851	3747
M. 68. OS. l.	4102,85	1,08715	[illegible]
M. 68. OS. r.	4295,85	1,08705	4670
W. 38. K.	4407,05	1.1300	4980 †
W. 26. OS. l.	4492,1	1,0514	4723
W. 26. OS. r.	4643,0	1,0532	4890
M. 30. OS. l.	5515,9	1,0564	5827
M. 30. OS. r.	5637,5	1,0549	5947
M. 40. OS. l.	6951,46	1,0598	7367
M. 40. OS. r.	7099,15	1,06586	7567

1) Volume in cubic centimeters; 2) specific gravity; 3) absolute weight in grams.

It will be evident from this table how small the influence of specific gravity actually is and how little it disturbs the parallelism of the two columns (one containing the volumes and the other the weight values). The series is broken only at two points — namely, where the values for the head of the 28-year-old woman and for the right shank of the 68-year-old man are entered in the table with the †. Only in these two cases is the specific gravity disproportionately higher, so that it moves the volumes of the corresponding parts one or two steps higher.

The second striking fact noted on examination of the table is that with only two exceptions, which are keyed with the *, all sections of the extremities separate into sharply differentiated groups. Only the forearm of the esthetically built man, the weight of which falls into the same series as the upper-arm weights, and his upper arm, which breaks the series formed by the shanks of the other cadavers, disturb this perfectly distinct separation. However, in no way do I wish to represent this separation as a generally valid

law, and therefore designate these two cases only as exceptions in the present series, and not as exceptions to any type of rule.

The specific gravities array themselves in an ascending order quite different from that of the volumes or absolute weights, namely:

(1.1300)			
W. 38. K.	M. 68. H. r.	M. 30. OA. r.	
M. 68. US. l.	M. 30. VA. r.	M. 30. OA. l.	
M. 68. US. r.	M. 68. H. l.	M. 68. OS. l.	W. 26. US. l.
M. 30. H. r.	M. 40. VA. r.	M. 68. OS. r.	W. 26. US. r.
M. 30. H. l.	W. 26. F. r.	M. 30. US. r.	M. 40. F. l.
W. 20. H. r.	M. 68. F. l.	M. 30. US. l.	M. 40. OS. r.
M. 40. H. r.	W. 26. F. l.	M. 40. US. l.	W. 20. OA. r.
M. 30. VA. l.	M. 68. F. r.	M. 40. US. r.	M. 40. OS. l.
M. 68. VA. r.	M. 68. OA. l.	M. 30. K.	M. 30. OS. r.
M. 68. VA. l.	M. 30. F. r.	M. 40. OA. r.	M. 30. OS. r.
	M. 30. F. l.	W. 20. VA. r.	W. 26. OS. r.
	M. 68. OA. r.	M. 40. F. r.	W. 26. OS. l.
			(1,0514)

From this we adduce the rule that age and sex must be taken into account in addition to the volume found in a particular case for a part of a living individual.

If, for example, we obtain a volume of 408 or 410 cubic centimeters for the hand of a 30-year-old [man], we do not take the specific gravity of the hand of the 68-year-old [man], the volume of which stands nearest to our figure in the table, but that of the average of the specific gravities shown by the hands of the 30- and 40-year-old men in the table.

The other parts of the body are dealt with in the same way as the individual pieces of the extremities, using the lower and upper pieces of the torso to displace water from the hogshead and finally immersing the head to determine its volume from the weight of water.

If we have determined the volumes and from them the weights of all the individual parts, we have a means to check the correctness of the observations and computations in the form of the balance, on which the individuals are placed before the experiments begin and

after the whole series has been completed.

Since, as shown by the table (sub I), the distances of the centers of gravity on the individual parts of the body, expressed as fractions of the total height, show very small variations, and the variations of the relative averages of their distances from the end points of the members vary even less, the table is alone sufficient for approximate determination of their loci for any other living male individual.

We can gain our object with even higher accuracy by detouring through calculation. It was indicated in the first report that various observers, working on different cadavers, have come to the same result as regards the anatomical location at which the center of gravity of an entire extremity, the entire torso, etc., must be sought. Thus, it is the plane of the processus xyphoidens for the torso, the plane of the elbow-joint pivot axis for the upper extremity, and the plane of the upper margin of the patella for the lower extremity.

The formula $X = (mx + m_1x_1 + m_{11}x_{11})/(m + m_1 + m_{11})$ can always be used to check whether the positions assumed for the centers of gravity, i.e., the x for the formula, have been correctly selected; where this is not the case, they are corrected in accordance with probability within the limits of the actually very small differences that occur here.

For the two large sections of the torso, the locus can be sought in accordance with the bases found by direct measurements for the formulas used above and similarly checked by investigating to determine the anatomical position at which the center of gravity of the entire torso is placed as a result.

Finally, a final control experiment for all of the weight deter-

minations and the distribution of the centers of gravity in the individual members can be made by balancing the entire human individual in the supine position on the tilting board, using Weber's method, thereby determining the distance of the over-all center of gravity from the plane of the crown of the head. When this is done, we investigate to determine where the same point is placed as a result, either by calculation with the mechanical seesaw, whose weights have been corrected in accordance with the results – which is easily done by removing their threaded caps.

If we have precision measuring instruments for the quantity of water overflowed, e.g., precision-made cylinders with side-mounted graduated riser tubes, it will be seen that it is possible to weigh the individual parts of the body and check the entire calculation by Weber's experiment by determination of the volumes, and without using a balance.

For example, we used this method in the case of a 24-year-old man, the weight of whose hand we set equal to unity; the following values were found for the sections of the extremities:

Foot	2.09
Shank	5.10
Thigh	13.854
Forearm	2.21435
Upper arm	3.3883

On comparison with the averages of the corresponding weights for the two executed specimens, this gives

the small differences of	-0.2461	for the foot
	-0.35	for the shank
	-0.258	for the thigh
	+0.1288	for the forearm, and
	-0.369	for the upper arm.

The average value of these differences is smaller than that found for all of these parts in the two executed persons.

In a later report, if I have managed to assemble sufficient data,

I shall publish more detailed comparisons of the relative weights shown by the members of living individuals having greatly differing physiques; here, I content myself only with the proof that the method indicated for making these comparisons possesses sufficient accuracy.

The use of values found in this way for the static moments of all the individual component masses to determine the position of the over-all center of gravity and the weight vector in a given attitude of the body is simple after correction of the weights on the seesaw, and can lead us to our objective by either of two routes: either by preliminary photography of the event or by preliminary measurement.

Finally, the two methods require further brief discussion. The more difficult the attitude to be investigated in this respect, the more necessary does it become to take the so-called positive photographs on glass plates instead of the negative photographs. With good illumination, the former require only one second, and can be rendered more contrasty in an extremely convenient manner by sublimate solution, which is poured over them after fixing. For the sake of the measurements to be made, it is well, so as not to be deceived by the thickness of the glass, to cover the image surface with rubber or transparent varnish and trace the photographed lines in question, which correspond to the horizontal plane of the individual centers of gravity (these have been drawn previously, as determined, on the living individuals with colored marks or dots), onto paper, and then to begin with the measurements.

It is understood that the event [motion] is photographed from the side on which foreshortening is least pronounced and the plane of displacement of the weight vector being investigated runs parallel

to the image plane.

It is similarly necessary to select the appropriate camera-to-subject distance and to place the optical axis of the instrument halfway up the height of the entire body in the attitude involved.

A perpendicular is erected next to the figure and at right angles to its base surface on the paper onto which at least all of the individual centers of gravity with their designations have been transferred, and the distances of the centers of gravity of all the individual members are measured.

The appropriate weights are set on the seesaw at the positions given by the measurements, and the counterweight is adjusted so that the instrument's indicator settles on zero.

The distance between the center of gravity of the counterweight and the fulcrum in this case corresponds to the distance of the body's weight vector in the photographed attitude from the perpendicular erected next to the figure, and hence also to the position at which it strikes the supporting surface.

The other method, which involves finding the reciprocal positions of the centers of gravity one at a time by direct measurement, is more circuitous, but also more accurate; this entails projection onto the plane on which the figure is standing in the attitude in question. It requires more time and is consequently used only in the less difficult attitudes.

For this purpose, I used one of a series of rods corresponding to the individual parts of the body; these have round sections and stand 4-9' high. A 1/2'-long horizontal arm can be shifted along each of these rods, and secured at any height on it with a setscrew. This arm terminates in a wire 1 1/2 lines in diameter, which is grooved vertically at its most anterior point. A silk thread is attached

to the point of the rod. This carries a small conical steel plummet. Each rod bears the name of the part of the body for which it is used.

The model to be investigated steps onto a horizontal platform that is divided into squares one centimeter on a side and assumes the required attitude. Lines are drawn on his body to represent the horizontal planes of the centers of gravity. As soon as the proper attitude has been struck, the observers shift the horizontal arms of the rods to the lines of the centers of gravity, following a plan worked out in advance in accordance with the specific circumstances, so that the appropriate photographs of the half thickness of each individual part can be made without additional fumbling for the particular purpose of the investigation, i.e., for determination of the displacement of the center of gravity forward, backward, or to the right or left. Then the model walks off the divided surface, taking care not to disturb any of the rods, and next the threads with the plummets are laid over the notches on the wires carried by the horizontal arms of the rods and the points of their contact with the individual parts of the body projected onto the divided surface. The locus of the over-all center of gravity is determined from the readings noted on this surface, using the first method.

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